Physical properties and tillage of Paleudults in the southeastern Coastal Plains

R. B. CAMPBELL, D. C. REICOSKY, and C. W. DOTY

ABSTRACT—Physical properties of some soils of the southeastern Coastal Plains restrict deep plant root development. Soil physical impedance to root elongation and low water-holding capacity, combined with periods of low rainfall, cause severe water stress in plants. Soil physical properties affecting root and shoot growth and subsequent soil management practices include particle-size distribution, soil strength, water retention, and soil water transmission. The high bulk density of the A2 horizon in many Typic Paleudults arises from their particle-size distribution and particle arrangement. Under tillage, the predominant horizons (Ap, A2, and B) are further compacted when water content is best suited for plant growth. Chiseling soil to a 38-centimeter (15-inch) depth disrupted the A2 horizon, reduced root impedance, increased infiltration, and increased rooting depth. Lowering strength of the restricting layer increased soil-water availability by decreasing the water content at which the critical strength for root development was encountered. The strength of the B horizon was less than the limiting value for root growth over a wide range of water content. Deeper root proliferation enabled plants to extract water from a larger volume of soil, which minimized plant water stress and increased yields. During drought, chiseling without irrigation increased crop yields from 38 to 81 percent. Soils with a high-strength A2 horizon can be managed by using water management practices that keep the surface layers in the low strength range or by practices that disrupt the restrictive layer and enable root proliferation in the lower strength subsoil.

KNOWING how soil physical and chemical properties affect plant growth is essential in developing soil and water management guidelines for crop production. Some of these properties that relate directly to plant growth are soil strength, soil-water retention, and water transmission in the soil. Here we present some soil physical properties that affect root and shoot development in relation to deep tillage to improve root development and to alleviate, at least partially, plant water stress in soils with

R. B. Campbell and D. C. Reicosky are soil scientists and C. W. Doty is an agricultural engineer at the Coastal Plains Soil and Water Conservation Research Center, Southern Region, Agricultural Research Service, U. S. Department of Agriculture, Florence, South Carolina 29501. This article is a contribution from ARS in cooperation with the South Carolina Agricultural Experiment Station.

Reprinted from the Journal of Soil and Water Conservation
September-October 1974, Volume 29, Number 5

dense layers in the southeastern Coastal Plain.

Soil Physical Properties

Southeastern Coastal Plain soils extend from Virginia to eastern Texas at elevations of 100 to 500 feet. They are bounded by the Atlantic and Gulf flatwoods on the southeast and by the Piedmont on the northwest. Topography is nearly level to moderately sloping, with slight to moderate erosion.

The area has a warm-temperature climate and a 200- to 250-day growing season. Precipitation averages 117 cm (46 inches) a year; 71 cm (28 inches) falls during the growing season. Drought may occur any time.

Soils are primarily Ultisols developed from unconsolidated sand and clay sediments. The weak granular, sandy surface horizon often contains less than 2 percent organic matter and generally not more than 3 percent (*11*).

Like many soils with an A2 horizon of pedogenic origin (*7*) in the southeastern Coastal Plains, about 58 percent of the soils in Florence County, South Carolina, have an A2 horizon (*16*). The sand and silt fractions of this horizon are composed mainly of quartz and small amounts of other resistant minerals. The clay fraction is primarily kaolinite and a small fraction of 2:1 to 2:2 intergrade minerals. Illuviated B horizons immediately below the A2 horizon often are strongly to very strongly acid and contain little organic matter.

Mechanical Composition

Textures of surface horizons in Norfolk (Typic Paleudult), Varina (Plinthic Paleudult), and related soils usually are sand, loamy sand, or sandy loam. The B horizons are predominantly sandy clay loam for Norfolk and sandy clay for Varina. Textural variations of sand, silt, and clay expressed as the mean percentage and standard deviation for 10 profiles of the Norfolk series from Alabama, Georgia, Mississippi, South Carolina, and Virginia (*19*) are listed below:

Horizon	*Sand*	*Silt*	*Clay*
	Mean % ± Standard Deviation		
Ap	77 ± 5	17 ± 5	6 ± 2
A2	72 ± 7	18 ± 5	10 ± 7
B	63 ± 7	17 ± 8	20 ± 10

Similar data from the Sandhill region and upper Coastal Plain of North Carolina show that A2 horizons usually contain less than 10 percent clay (*7*).

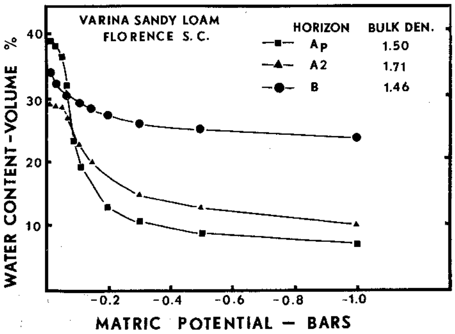


Figure 1. Water retained at different matric potential levels for three horizons of a Varina sandy loam.

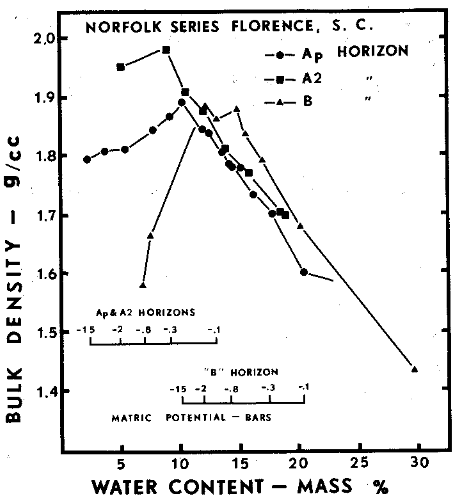


Figure 2. Bulk density for Ap, A2, and B horizon materials of a Norfolk soil compacted at different initial water contents.

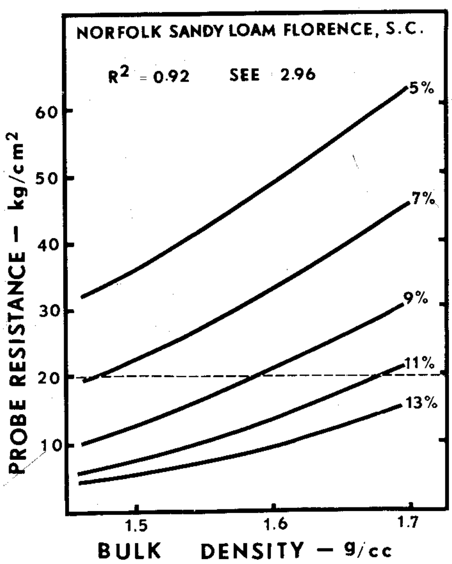


Figure 3. Probe resistance (soil strength) related to water content (mass percent) and bulk density for the surface layer of a Norfolk soil.

Soil-Water Retention

Retention and movement of water in soils are major factors related to plant water stress. Water received by the soil from precipitation or irrigation becomes part of a dynamic system in which water gradients arising from gravity and evaporation tend to equilibrate with forces in the soil matrix. Available water for plant use depends on the root system, transpirational demand, and competition among evaporation, gravity, and other internal forces. Capillary forces that hold water in soil pores generally increase as pore size decreases. Consequently, more energy is required to remove water from small pores than from large pores. The amount of soil water retained at a given matric potential (energy of water retention by soil, usually expressed in bars or atmospheres) is related to the volume of pores equal to or less than a given size.

The water-retention curves in figure 1 show the relation between percent soil water and matric potential values for the Ap, A2, and B horizons of a Varina sandy loam. These measurements were obtained from soil cores equilibrated on porous plates in pressure chambers (*20*) at matric potentials between −0.01 and −1.0 bar. They are typical of Paleudults in the South Carolina Coastal Plain. Nearly 42 percent of the total pore volume in the Ap horizon of this soil was drained between −0.01 and −0.1 bar, compared with 17 percent for the more dense A2 horizon. However, the Ap and A2 horizons release nearly the same amount of water within the matric potential range of −0.1 to −1.0 bar. Release of water from the B horizon is more gradual than in the surface layers within the −0.01- to −1.0-bar range. Lutz (*12*) reported a 46 percent release (expressed as percent of total porosity) from the B horizon of a similar soil, compared with 8.3 percent from the Ap horizon within the −1.0- to −15.0-bar range. The surface horizons of these sandy loam or loamy sand soils release most of the water at high matric potentials and relatively little beyond −1.0 bar. The B horizon release water more uniformly, with a relatively larger proportion released in the range of −1.0 to −15.0 bars.

Water availability to plants is not determined solely by soil-water retention characteristics. Root development and soil-water conduction are influential factors also. Water-retention curves are used to determine unsaturated conductivity for water flow calculations (*10, 15*) and for development of sound irrigation practices.

Soil Compaction

Compactness as well as soil particle size influence water retention. Small, single-grained particles that fill pores between larger particles increase soil bulk density.

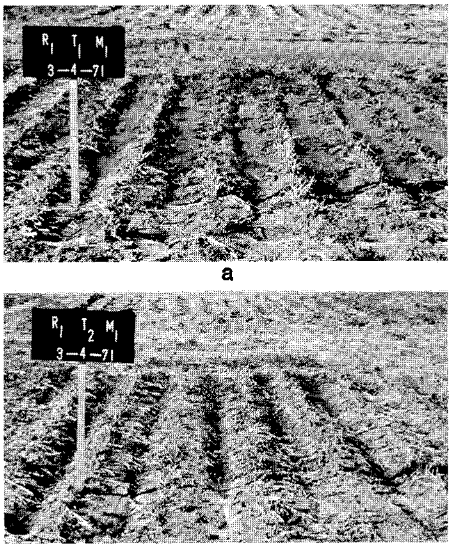
The A2 horizon of a Norfolk soil near Florence, South Carolina, contained 78.6, 18.1, and 3.2 percent sand, silt, and clay, respectively. A comparison of these particle-size analyses with those of Bodman (*3*) showed that compaction of the Norfolk A2 horizon very likely would result in a low void ratio and high bulk density.

Field bulk density values of the Norfolk soil at Florence averaged 1.50, 1.67, and 1.50 gm/cm^3 for the Ap, A2, and B horizons, respectively. Lutz (*12*) reported that the bulk densities of seven A2 horizons in North Carolina exceeded those of the Ap horizons. In addition, the bulk densities of the A2 horizons equaled or exceeded those of the B horizons for six of the seven profiles. Apparently, the particle-size distribution of the A2 horizon contributes to its natural high bulk density and compactness.

The degree of soil compaction, determined from the standard Proctor test (*17*) at various initial water contents, is presented in figure 2 for the Ap, A2, and B horizons of a Norfolk soil. These horizons are readily compacted within the soil water range best suited for plant growth. The greatest degree of compaction of the Ap horizon was at a water content of 11 percent (−0.2 bar), whereas the A2 horizon compacted to the highest bulk density at a water content of 8 percent (−0.4 bar). The B horizon was most readily compacted at a water content of 13 percent (−1.0 bar).

Soil Strength

Physical impedance to root growth depends on the type of soil, bulk density, and water content (*1, 22*). Although impedance at the growing tip of a root is difficult to measure, soil probes offer a means of characterizing soil strength in terms of probe resistance (force per unit area).



b

Figure 4. The influence of chiseling on infiltration: (a) shallow-tilled and (b) deep-tilled (chiseled). Note ponded water on the shallow-tilled plot after a heavy rain.

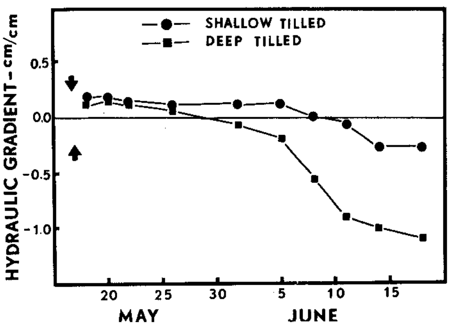


Figure 5. Hydraulic gradient during a drying cycle in shallow-tilled and deep-tilled (chiseled) soil shown as a function of time at the 107-cm (42-inch) depth in a field of millet. Arrows indicate direction of flow.

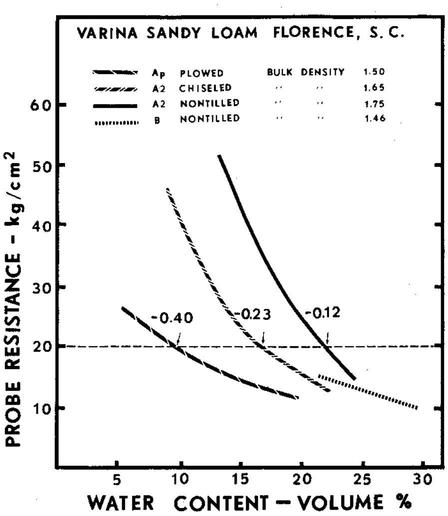


Figure 6. Probe resistance (soil strength)—water content relationship for different horizons of a Varina sandy loam. The dashed line indicates probe resistance that restricts root growth. Numbers on curves indicate matric potential in bars.

The family of curves relating bulk density and water content to probe resistance in figure 3 was obtained on undisturbed cores collected in the field and equilibrated after wetting in pressure chambers over a range of −0.1 to 2.0 bars matric potential. Penetration resistance was then measured with a blunt 5-mm-diameter probe and used as an index of soil strength.

Probe resistance increased with increasing bulk density but decreased with increasing water content. Taylor and associates (*23*) found, and we have since verified, that root growth is sharply impeded when soil strength exceeds 20 kg/cm^2. In figure 3, the horizontal dotted line represents the level of strength at which root elongation is severely suppressed. As bulk density increases, the soil water content necessary to maintain strength at or lower than 20 kg/cm^2 also increases. For example, the Norfolk soil with a bulk density of 1.68 g/cm^3 must be wetter than 11 percent water (mass basis) or a matric potential greater than −0.12 bar for the soil strength to be less than the critical 20 kg/cm^2. At a bulk density of 1.47 g/cm^3, the soil can dry to about 7 percent water or a matric potential of −0.80 bar before the critical soil strength is attained. These data demonstrate how soil strength, measured with soil probes, varies with bulk density and water content in a soil with a fixed particle-size distribution.

Effects of Chiseling Paleudults

Infiltration

In areas where rainfall during the cropping season occurs as high-intensity storms, soil management practices that increase infiltration will necessarily decrease the amount of runoff and erosion. In our work, the soil containing a compact A2 layer at the 18- to 30-cm (7- to 12-inch) depth was chiseled every 25 cm (10 inches) to a depth of 38 cm (15 inches) to modify surface and subsurface conditions.

Figure 4 shows the influence of chiseling on the amount of water ponded on the soil surface 12 hours after a 3-day rainy period in which precipitation totaled 19 cm (7.5 inches).

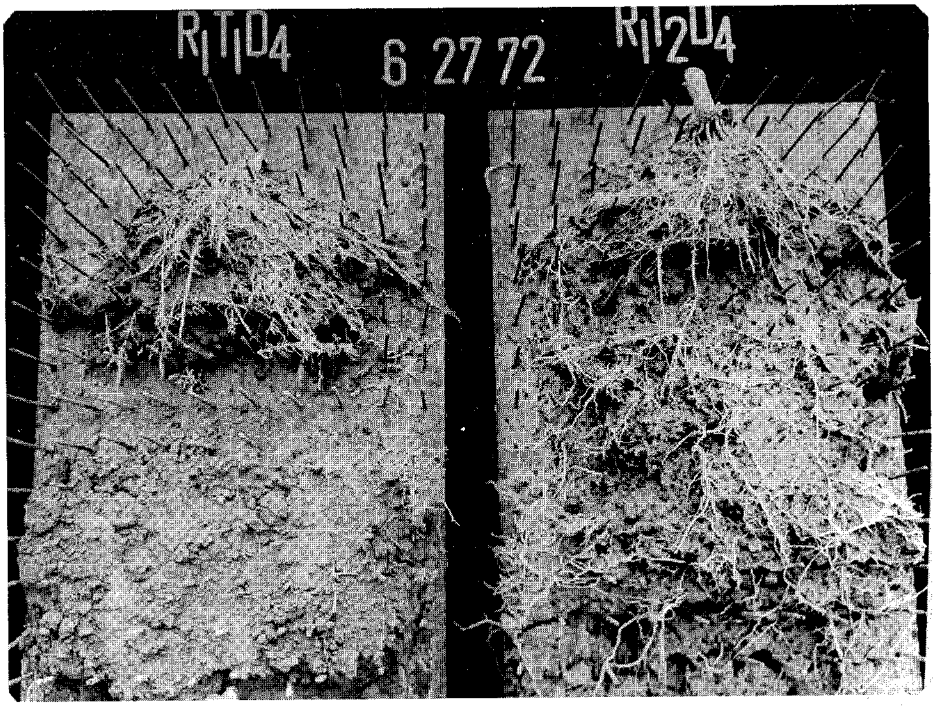


Figure 7. Rooting in a shallow-tilled (left) and deep-tilled (chiseled) soil. Roots in the deep-tilled soil penetrated to 30 inches. Roots in the shallow-tilled soil were confined to the plow layer above the restricting A2 layer of a Varina sandy loam.

Higher infiltration in the chiseled plot was partially attributed to a lower density in the A2 horizon. The textural differences of the layers within the profile impart flow properties that apparently decreased the flow rate through the soil and, hence, the infiltration rate. Miller (*14*) showed that a layer of distinctly different physical properties can decrease the rate of water movement through the profile. This change in flow rate, whether due to a layer with a different texture or a change in saturated conductivity, increases the water in the surface layer, decreases the infiltration rate, and can result in poor soil aeration. Tobacco shows symptoms of oxygen stress within 12 hours after flooding due to heavy rainfall on Paleudults (*4*). Aggregate stability of the surface layer and type of surface cover further compound interpretation of infiltration rates (*2*).

Hydraulic Gradient

Figure 5 illustrates the effect of chiseling on water movement in the soil profile during a drying cycle for millet. This graph shows the hydraulic gradient at the 107-cm (42-inch) depth as a function of time during drying. When the gradient is positive, water moves below the 42-inch depth. When the gradient is negative, water moves upward to the soil surface within the root zone. The direction of flow at the 42-inch depth changed from downward to upward about 10 days earlier in chiseled soil than in shallow-tilled soil. This suggests a more extensive root system in the deep-tilled soil. The additional water extracted from the subsoil of the deep-tilled soil was related to increased vegetative millet yield.

Strength of Deep-tilled versus Shallow-tilled Soils

Particle size, bulk density, and water content of the A2 horizon directly influence soil strength. After a field soil settles, little or no change in particle-size distribution and bulk density occurs; therefore, soil strength becomes essentially a function of water content.

Results of an investigation of the soil strength-water content relationship of a Varina sandy loam for the Ap, A2, and B horizons in a shallow-tilled soil and at the corresponding depth of the A2 horizon in a deep-tilled soil are presented in figure 6. In general, probe resistance increased as water content decreased. The water content at the limiting resistance for the nontilled A2, chiseled A2, and plowed Ap soil was 22, 17, and 10 percent, respectively. The order of decreasing resistance at the same water content was A2 nontilled, A2 chiseled, and Ap plowed, respectively. Probe resistance of the B horizon was less than 15 kg/cm^2 at 21 percent water content (−2.0 bars), and resistance to root growth was only moderate.

Although several factors influence soil strength, the relation of probe resistance to matric potential, at which root growth is limited, often can be useful. Matric potential values (Figure 6) corresponding to a probe resistance of 20 kg/cm^2 were −0.40, −0.23, and −0.12 bar for the Ap plowed, A2 chiseled, and A2 nontilled, respectively. These data indicate that soil strength may limit root development long before water available to plants is extracted. When root elongation is limited by high strength, the water needed to meet plant transpiration demands depends on soil water flow processes. These processes generally are too slow to meet plant needs.

Paleudults with A2 horizons that restrict root growth can be managed by using water management practices that resupply water to the surface layer or by using tillage practices that physically disrupt the restricting layer to allow root development in the lower strength B horizon.

Root Growth

In our study of the influence of chiseling on rooting patterns of corn growing in a Varina sandy loam, soil monoliths 76 cm (30 inches) high, 61 cm (24 inches) wide, and 15 cm (6 inches) thick were used to assess root distribution.

The partially washed monolith in figure 7 (on the left) shows that most roots were confined to the Ap horizon in the shallow-tilled soil. When the A2 horizon of the monolith was removed by washing, exposed root growth appeared to be confined to the Ap layer on the top of the A2 horizon. There were essentially no roots in the subsoil. The other monolith in figure 7, taken from a chiseled plot, showed many roots present in the subsoil to a depth of 76 cm (30 inches). This increased root proliferation let plants extract water from a larger volume of soil, thereby minimizing plant water stress and increasing corn yields.

Crop Response

The influence of chiseling on the vegetative yield of millet with and without irrigation during the 1970 growing season is shown in figure 8. With irrigation, chiseling did not appreciably increase yields over nonchiseling. However, in the early part of the growing season, with inadequate rainfall, chiseling without irrigation resulted in yield increases that ranged from 38 to 81 percent more than that of nonchiseled, nonirrigated millet. From mid-July to the end of the season, because of frequent rainfall, chiseling had no beneficial effect. Increased millet yields during drought in chiseled soil was attributed to increased soil water availability due to deeper rooting. Chiseling thus seemed as beneficial as irrigation during short-term drought.

Beneficial effects of chiseling decrease with duration of drought because of the subsoil's low water-holding capacity. Data in figure 8 show an 81 percent yield increase for the chiseled treatment over the nonchiseled treatment for the first cutting and a 40 percent yield increase for the second and third cuttings during an extended drought.

Management Concepts

Although deep plowing, chiseling, subsoiling, and soil modification encourage deep root development, they are no panacea for all crop production problems. Because crop production depends upon soil, climate, and many other factors (*5*, *21*), their interdependence is important in applying tillage to cropping practices. Deep tillage generally is effective when the soil's physical and chemical properties restrict rooting in regions where rainfall is limited or poorly distributed. Deep plowing has successfully reclaimed certain types of sodic soils (*18*). In a Pullman silty clay in Texas, deep disk plowing increased infiltration, but the sorghum yield increased in only 1 of 3 years (*8*). In Freeman silt loam in Washington, deep plowing with natural precipitation resulted in a higher water content, greater root proliferation, and consistent increases in pea, wheat, and alfalfa yields (*13*). Heilman and Gonzalez (*9*) tested narrow, backfilled trenches (10 cm wide by 61 and 102 cm deep) in a very fine montmorillonitic clay as a management technique to increase rooting depth and volume. They found increased cotton yields, higher infiltration rates, lower bulk densities, and greater rooting volumes. This procedure may be applicable on Coastal Plain soils with compact layers in the root zone. Mixing the Ap, A2, and portions of the B horizon in narrow trenches 10 to 15 cm wide under the plant row may enhance deeper rooting and increase water use. Another alternative is relocating the three horizons to achieve rooting in the more fertile surface soil and using the less desirable soil for traffic.

Our experiments and those by Ford and his colleagues (*6*) clearly demonstrate that both rainfall distribution and soil properties must be recognized in developing management practices to effectively use soil and water resources in the Coastal Plains. In areas where the soil's water-holding capacity is low and compact layers restrict deep root development, deep tillage and/or soil modification can benefit many crops. Increased rooting by deep tillage may only partially relieve drought stress, however, because the effectiveness of deep tillage depends largely on the duration of drought. For this reason, deep tillage of certain soils should be considered an intermediate alternative in the absence of irrigation.

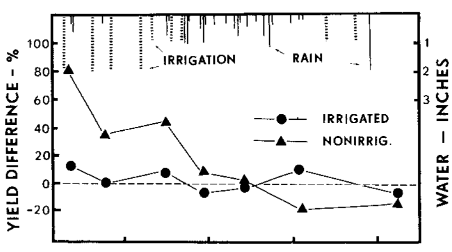


Figure 8. Change in yield attributed to deep tillage (chiseled) in an irrigated and nonirrigated field of millet.

REFERENCES CITED

1. Barley, K. P., D. A. Farrell, and E. L. Greacen. 1965. *The influence of soil strength on the penetration of a loam by plant roots.* Aust. J. Soil Res. 3: 69-79.
2. Beale, O. W., T. C. Peele, and F. F. Lesesne. 1966. *Infiltration rates of South Carolina soils during simulated rainfall.* Tech. Bul. 1022. S. C. Agr. Exp. Sta., Clemson.
3. Bodman, G. B., and G. K. Constantin. 1965. *Influence of particle-size distribution on soil compaction.* Hilgardia 36: 567-591.
4. Campbell, R. B. 1973. *Flue-cured tobacco yield and oxygen content of soil in lysimeters flooded for various periods.* Agron. J. 65: 783-786.
5. Doty, C. W., and J. L. Wiersma. 1969. *Geometric shaping and contouring of land as related to potential for surface-water storage.* Trans., ASAE 12: 322-325, 328.
6. Ford, Z. T., J. F. Chaplin, and T. W. Graham. 1964. *Effects of subsoiling and soil fumigation on flue-cured tobacco.* Bul. 514. S. C. Agr. Exp. Sta., Clemson.
7. Gamble, E. E., R. B. Daniels, and R. S. McCracken. 1970. *A2 horizons of Coastal Plain soils pedogenic or geologic origin.* Southeastern Geol. 11: 137-152.
8. Hauser, V. L., and H. M. Taylor. 1964. *Evaluation of deep-tillage treatments on a slowly permeable soil.* Trans., ASAE 7: 134-136, 141.
9. Heilman, M. D., and C. L. Gonzalez. 1973. *Effect of narrow trenching in Harlingen clay soil on plant growth, rooting depth and salinity.* Agron. J. 65: 816-819.
10. Jackson, R. D., R. J. Reginato, and C. H. M. van Bavel. 1965. *Comparison of measured and calculated hydraulic conductivities of unsaturated soils.* Water Resources Res. 1: 375-380.
11. Lee, W. D. 1955. *The soils of North Carolina.* Tech. Bul. 115. N. C. Agr. Exp. Sta., Raleigh.
12. Lutz, J. F. 1969. *The movement and storage of water in North Carolina soils and the role of the soil in determining water quality.* Rept. No. 24. N. C. Water Resources Res. Inst., Raleigh.
13. Mech, S. C., G. M. Horner, L. M. Cox, and E. E. Cary. 1967. *Soil profile modification by backhoe mixing and deep plowing.* Trans., ASAE 10: 775-779.
14. Miller, D. E. 1969. *Flow and retention of water in layered soils.* Cons. Res. Rept. 13. U. S. Dept. Agr., Washington, D. C. pp. 1-28.
15. Millington, R. J., and J. P. Quirk. 1960. *Transport in porous media.* Trans., Seventh Int. Cong. Soil Sci., Madison, Wisc. pp. 97-106.
16. Pitts, J. J. 1974. *Soil survey Florence and Sumter Counties, South Carolina.* Soil Cons. Serv., U. S. Dept. Agr., Washington, D. C.
17. Proctor, R. R. 1933. *Fundamental principles of soil compaction: Description of field and laboratory methods.* Eng. News Rec. 3: 286-289.
18. Rasmussen, W. W., G. C. Lewis, and M. A. Fosberg. 1964. *Improvement of the Chilcott-Sebree (solodized-Solonetz) slick spot soils in southwestern Idaho.* ARS 49-91. U. S. Dept. Agr., Washington, D. C. 39 pp.
19. Rich, C. I., et al. 1959. *Certain properties of selected southwestern United States soils and mineralogical procedures for their study.* Southern Coop. Series Bul. 61. Va. Agr. Exp. Sta., Blacksburg.
20. Richards, L. A. 1948. *Porous plate apparatus for measuring moisture retention and transmission by soil.* Soil Sci. 66: 105-110.
21. Robertson, W. K., J. G. A. Fiskell, C. E. Hutton, L. G. Thompson, R. W. Lipscomb, and H. W. Lundy. 1957. *Results from subsoiling and deep fertilization of corn for 2 years.* Soil Sci. Soc. Am. Proc. 21: 340-346.
22. Taylor, H. M., and H. R. Gardner. 1963. *Penetration of cotton seedling taproots as influenced by bulk density, moisture content and strength of soil.* Soil Sci. 96: 153-156.
23. Taylor, H. M., A. C. Mathers, and F. B. Lotspeich. 1964. *Pans in the southern Great Plains soils. I. Why root-restricting pans occur.* Agron. J. 56: 328-332.